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LARGE SCALE EXCITATION OF THE ISM IN NGC 1068

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ABSTRACT:

We have shown that photoionization by the continuum of the hidden Seyfert I nucleus in NGC 1068 can have a significant effect on the ionization state and energetics of this disk's ISM. Photoionization models with appropriate power law spectra can produce [NII] $\lambda\lambda$ 6538, 6584/Hα line ratios of 1.25 for ionization parameters Q ~10^{-12}. However our data indicate large regions where the [NII]/Hα ratio is 1-3. Since the abundances are known to be solar, there must be additional heating sources. Hardening of the incident radiation field by intervening absorption should be able to raise T_e, thereby raising the [NII]/Hα ratio. Heating with moderate efficiency by the intense starburst ring should also be a significant factor in raising the temperature of the ISM. Our photoionization models with additional heating predict enhanced emission from other forbidden lines including [OII] λ 3727 and [SII] λ 6731.

INTRODUCTION:

NGC 1068 is a prototypical Seyfert II galaxy which has been the subject of considerable study due to its close proximity and wealth of interesting activity. There exists in the inner 15".0 a bi-polar radio jet, a stellar bar as well as an elliptical ring of intense star formation, with semi-major axis parallel to both the bar and radio jets. That NGC 1068 harbors a hidden Seyfert I nucleus has been established by the detection of a typical broad-lined spectrum in scattered polarized light [Antonucci and Miller, 1985] as well as by the detection of broad Fe II nuclear line emission [Snijders, Netzer and Boksenberg, 1986]. Theoretical work [Krolik and Begelman, 1986] suggests that the Seyfert I nucleus is hidden from view by an optically and geometrically thick torus, which is the source of an electron wind boiled off of its inner surface. Detailed kinematical analysis of our Fabry-Perot data indicate that this torus has an opening angle of ~85°, and symmetry axis inclined 35° out of the plane of the disk. This implies that the Seyfert I nucleus beams substantially into the disk. NGC 1068 has been found to contain considerable quantities of spatially extended high excitation gas, particularly toward the northeast quadrant. Evans and Dopita, studying HII regions in NGC 1068 [Evans and Dopita, 1986], have determined that their abundances are solar and their spectra are superpositions of a normal HII region component as well as a high excitation one, characterized by excessive [NeV] λ 3346, 3426 and He II λ 4686 emission.

Our data were obtained using the Hawaii Imaging Fabry-Perot Interferometer (HIFI) [Bland and Tully, 1988]. Summations over the separate monochromatic flux images in both Hα and [NII]$\lambda\lambda$ 6538, 6584, produce complete Hα and [NII] flux maps (see Fig. 1a). A flux ratio map of [NII]/Hα (see Fig. 1b) is characterized by regions where [NII]/Hα < 0.5, with line widths of ~100 km/sec, and by kinematically distinct, high excitation regions where 0.5 < [NII]/Hα < 3.0, with line widths typically ~350 km/sec.

LARGE SCALE EXCITATION:

1. Photoionization and heating by a Seyfert I power law continuum

The 100 eV to 10 keV nuclear spectrum of NGC 1068 can be characterized by a two component power law. To determine the shape of the spectrum throughout the disk of NGC 1068, we have employed a Monte Carlo calculation to simulate the scattering of radiation out of the beaming cone over the energy range of 7.5 eV - 1 MeV. The direct radiation within the beaming cone, as well as that scattered into the disk outside of the cone are given in Table 1. Due to the

energy independence of low energy Compton scattering the spectral index for the 0-5 keV component does not change. At higher energies the energy dependence of both the cross-section and the energy transfer to the electron tend to steepen the spectral slope.

TABLE 1.

ENERGY RANGE	SPECTRAL INDEX	FLUX AT 13.6 eV ($ergs/cm^2$ sec Hz)
	Within Cone	
0 - 5 keV	2.0	2×10^{-15} (1 kpc/D)^2
5 keV - 1 MeV	0.62	1×10^{-18} (1 kpc/D)^2
	Outside Cone	
0 - 5 keV	2.0	1×10^{-17} (1 kpc/D)^2
5 keV - 1 MeV	0.81	5×10^{-21} (1 kpc/D)^2

We have used the general purpose ionization code MAPPINGS [Evans and Dopita, 1985] to investigate the ionizing effects of such an input spectrum. We have modeled the photoionization by a geometrically thin spherical shell with volume filling factor 0.1 and density 1 cm^{-3}. Since the code has a high energy maximum of 5 keV we have chosen a spectral index of 2.0. We find that we are able to generate [NII]/Hα ratios of up to 1.25 for ionization parameters $Q \cong 10^{-12}$ where Q is defined by

$$Q = \frac{1}{N_{tot}C} \int_{13.6\,eV}^{5\,keV} \frac{J_\nu}{h\nu}\, d\nu$$

However these models can not simultaneously generate the high values of [NeV] $\lambda\lambda$3346, 3426 and HeII λ 4686 emission seen in the Evans and Dopita data. These values require ionization parameters an order of magnitude greater or more, indicating that these emissions may be spatially distinct.

We have calculated the Compton heating caused by photons of energies greater than 5 keV. For typical cooling rates for ionized gas of 10^{-24} N_e^2 $ergs/cm^3$ sec, we find that the additional Compton heating in the cone will only be significant for ionization fractions less than 10^{-1} and/or at very low densities, whereas the Compton heating off of the cone should be negligible under all realistic physical conditions.

2. Heating by the Starburst Ring:

It is difficult to determine the direct heating effect of the starburst ring on the extended disk of NGC 1068 due to the undetermined geometric and starburst parameters. However an estimate may be made by scaling up the starburst of M82 which is better understood. Using a scaling factor equal to the ratios of the IR luminosities of these two starburst systems, we can determine the SN rate in NGC 1068 to be $\cong$ 0.75/yr, which can generate $\cong 2 \times 10^{43}$ ergs/sec. Assuming a 3 kpc radius and 1 kpc thickness for the hot disk of NGC 1068 with a filling factor of 0.1 and mean filament density of 1 cm^{-3}, we need ~ 1% efficiency in converting SN energy into heat in the disk, to have a heating rate of 10^{-24} $ergs/cm^3$ sec, comparable to that of canonical heating/cooling rates.

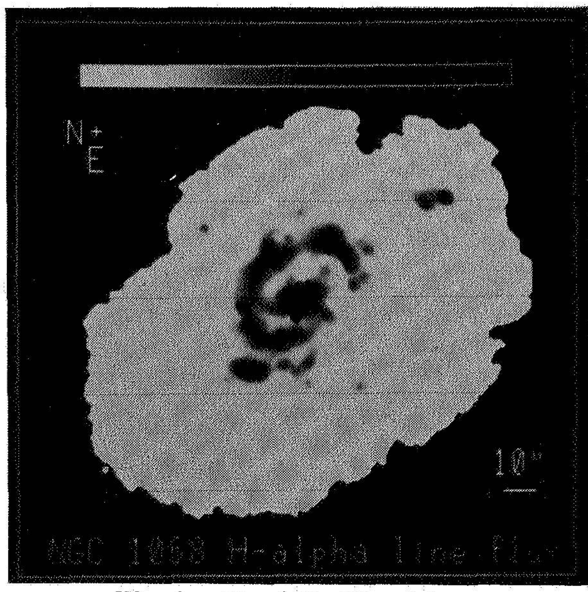

Fig. 1a. Total Hα Flux Map

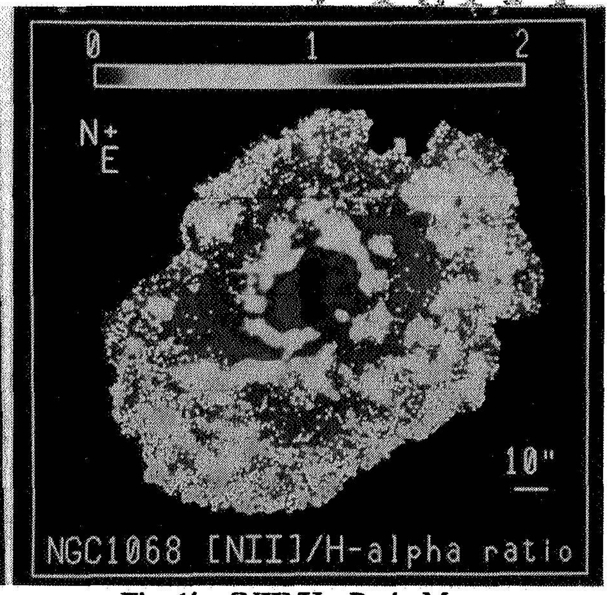

Fig. 1b: [NII]/Hα Ratio Map

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